The Health and Economic Cost of Coal Dependence in South Korea's Power Mix

April 2021

Centre for Research on Energy and Clean Air

CREA is an independent research organisation focused on revealing the trends, causes, and health impacts, as well as the solutions to air pollution.

Contents

Contents 1

Key Findings 4

Introduction 5

The State of Coal Power and Air Pollution in South Korea 6

Scope and Purpose of the Report 8

RESULTS 10

Emissions Load & Air Quality 10

Toxic Deposition 11

Health Impacts 13

Cumulative Cost of Coal Dependence, Past & Future 18

Recommendations 21

References 22

Appendix 1: Methods & Materials 24

Appendix 2: Stack Properties and Emissions Data 27

Appendix 3: Per-plant Results 30

About CREA

The Centre for Research on Energy and Clean Air is an independent research organisation focused on revealing the trends, causes, and health impacts, as well as the solutions to air pollution.

CREA uses scientific data, research and evidence to support the efforts of governments, companies and campaigning organizations worldwide in their efforts to move towards clean energy and clean air. We believe that effective research and communication are the key to successful policies, investment decisions and advocacy efforts. CREA was founded in December 2019 in Helsinki, Finland and has staff in several Asian and European countries.

Authors:

Lauri Myllyvirta

Isabella Suarez

Andreas Anhäuser

Contributors:

Minwoo Son

The maps used in this document were prepared in accordance with South Korean regulation.

CREA

Time for a Check Up: The Health and Economic Cost of Coal Dependence in South Korea's Power Mix

Key Findings

- Exposure to air pollution from coal-fired power plants (CFPPs) in South Korea is estimated to have caused approximately **9,500[1] premature deaths since 1983**, costing approximately **USD 16 billion** in healthcare and welfare expenditures, as well as loss of productivity and life expectancy.

- Pollution from 43 gigawatts (GW) of operating and in construction coal plants would cause over 720 premature deaths per year in the country. Approximately 30% of such deaths are linked to cardiovascular diseases, 11% to lower respiratory infections, 8% to lung cancer, and 8% to stroke as a result of exposure to elevated PM2.5 concentrations from the coal plants.
  - Nearly 45% of premature deaths in the country are estimated in Gyeonggi-do and Seoul. Other provinces and cities affected by pollution from coal power are Gyeongsangnam-do, Incheon, Chungcheongnam-do, and Jeollanam-do. These areas also bear the greatest economic cost burden as a result of this pollution.
  - Air pollution from the plants is also dispersed to neighboring countries. An additional 390 premature deaths, 60 new cases of child asthma, and 90 preterm births occur outside the country per year, amounting to approximately USD 270 million in cost.

- Health and economic impacts as a result of air pollution from coal in the country also include approximately 230 new cases of asthma in children, 80 preterm births, 280,000 days of work absence (sick leave days), and 370 asthma-related emergency room visits in South Korea every year.

- Despite strong emissions standards and other efforts to control emissions from the plants, they remain major contributors to air pollution. **Between today and the country's committed phaseout in 2054, coal-based power would be responsible for a cumulative 16,000 premature deaths within the country.** The associated costs from these health impacts are estimated at **USD 21 billion**.

[1] 95% confidence interval: 6,100 to 13,000.

Introduction

Coal combustion, one of the biggest historical and existing drivers of climate change and air pollution, is fast being replaced by renewable technologies like wind and solar in the global energy market. Existing and additional coal capacity, bolstered by continued flows of coal financing from various institutions, undermine efforts to urgently transition economies away from fossil fuel. The implications in both the short and long-term are increasingly costly in both the human and financial sense, as the literature and the impacts of planetary health on human health and the impacts of climate change increase. As countries plan for zero carbon transition and recovery from COVID-19, minimizing and removing the negative coal externalities as a major environmental and health threat should be considered.

South Korea is one such country grappling with coal's place in its energy and investment portfolio, both at home and abroad. Data shows that the country's public and private institutions have financed a total of $50 billion in coal projects and investments over the past decade, making the nation's stranded asset risk from coal one of the highest in the world. Domestically, the country's 60 operating coal-fired plants generate over 40% of its electricity. In 2017, emissions from the fossil fuel-dominated power sector accounted for 36% of South Korea's total greenhouse gas emissions. In addition, air pollution has worsened. In 2019, the nation's average concentration of ambient fine particulate matter (PM2.5) was the worst among the Organisation for Economic Cooperation and Development (OECD) member states, and three times higher than the World Health Organization's (WHO) recommended levels of exposure.

Public outcry over air pollution and climate issues have led to a national commitment to phase out coal by 2054. In their 9th Basic Plan for Electricity Supply and Demand 2020-2034, the Ministry of Trade, Industry and Energy announced that it would close 30 of its operating coal plants —about half the current fleet— by 2034. They also set a target to increase renewables' share in power generation capacity from 15% to 42% by 2034. In response and alignment, more than 100 of the country's financial institutions made a joint declaration to support sustainable finance to remove coal from their portfolios. Furthermore, in October of 2020, KEPCO declared to stop pursuing new coal power plant projects overseas.

Despite these announcements, the majority state-owned utility, Korea Electric Power Corp. (KEPCO), is expected to remain highly dependent on coal in the home country. While it has publicly stated its support for power sector decarbonization and the role of renewable energy to meet national policy targets, it has released no concrete plans to advance the pace of the energy transition. The country's installed coal capacity is still expected to increase from 36.3 gigawatts (GW) to 40 GW between now and 2030. KEPCO operates 95% of coal capacity in the country. It will also operate 5 of the 7 additional units that are scheduled to come online over the next 5 years.

While KEPCO is already under increasing pressure from investors over its coal financing, other financiers make it possible for the company to prolong coal dependence. For example, one of its most notable investors is South Korea's National Pension Service (NPS), whose coal exposure is the third largest in assets under management in the world. It has around US$ 10.6 billion invested in utilities including KEPCO and POSCO, largely through the acquisition of corporate bonds. Considering the challenge ahead and the compounding impacts from coal today, the lack of ambitious commitments and action from vital entities in the energy transition — such as KEPCO and NPS — could hamper South Korea's plans for a rapid coal phaseout.

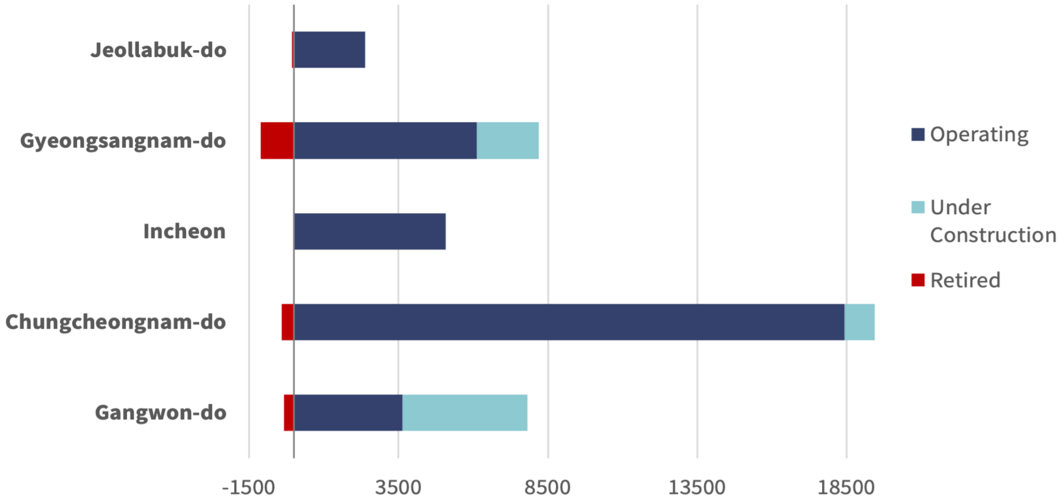
As a major source of air pollution, coal causes a range of adverse health effects, particularly mortality and morbidity due to cardiovascular and respiratory diseases. These health impacts affect other sectors, and have been shown to reduce labor productivity and increase health and welfare expenditures. A 2020 study found that the economic health benefits could outweigh the total costs of climate change mitigation in South Korea. As renewable energy technologies are becoming increasingly more affordable and competitive, coal makes little to no financial sense. Furthermore, reports of underutilized coal plants also increases the likelihood of new coal projects becoming stranded assets before the end of their useful life.

Coal dependence exposes large numbers of the population to elevated levels of air pollution. In this report, we assess the health and economic impacts of coal-based power as it relates to air pollution. To assess the full impact of coal use in the country, the past and future impacts from resulting air pollution in South Korea are quantified.

The State of Coal Power and Air Pollution in South Korea

South Korea's total installed coal capacity is equivalent to 36.4 gigawatts (GW). Plants are concentrated in 6 provinces, creating 3 major coal clusters in the North East, West and Southern coasts of the country (see Figures 2 and 3). This affects the dispersion of pollution to the surrounding areas. South Korea has only retired 5 coal plants - equivalent to just 1,920 MW and built between 1970 and 1985. More than 68% of currently operating plants were built in the last two decades. Without intervention, these coal plants are likely to operate over at least a 30-year operating life.

Figure 1: Capacity (MW) of coal-fired power plants and new projects in South Korea, by province and status[2]



SOURCE: Global Energy Monitor

As previously stated, this is a significant domestic issue because coal is one of the largest contributors to air pollution in the country, which causes adverse health impacts borne by the Korean people. Pollutants like particulate matter (PM2.5) are respirable. Considered one of the most dangerous pollutants, PM2.5 particles can be inhaled deep into the lungs and bloodstream, increasing the risk of developing respiratory and cardiovascular disease with continuous exposure over time. Nitrogen oxides (NO and NO2, collectively referred to as NOx), along with sulfur dioxide (SO2) that are also emitted from coal burning, react with water to form acid rain, snow and fog, and with other substances in the air to form particulate matter and smog. The health impacts of exposure to these gases include cardiovascular diseases, exacerbated symptoms of asthma, chronic obstructive pulmonary disorder and other respiratory diseases.

To minimize emissions from the stack, South Korea has been updating its emission controls standards under the Clean Air Conservation Act. Additionally, in an effort to control emissions during high pollution seasons, the government also ordered some coal plants —particularly those 30 years and older — to temporarily shut down during the winter period last year. Reports showed that coal plants operating during shutdown periods were operating no higher than at 80% capacity. Coupled with the reduction in activity due to COVID-19 restrictions, these efforts saw annual average PM2.5 concentration in 2020 decrease to 24 µg/m^3 from 33 µg/m^3 in 2019. While this indicates progress, such measures are unsustainable and still insufficient in meeting the WHO guidelines. Taken in consideration with the concerns presented in the previous section, it also raises more questions on the need for additional coal projects.

[2] excludes power plants with less than 400 MW of capacity, amounting to 730MW of operating capacity.

Scope and Purpose of the Report

This report uses detailed plant-by-plant emissions data that covers all the coal plants listed in Table 1 to calculate pollutant emissions of each coal plant. Using peer-review methods and literature outlined in Appendix 1: Methods & Materials, it models the dispersion of emissions from these plants and quantifies the health impacts from coal-fired air pollution in South Korea, focusing specifically on how the plants' pollutant concentrations alone contribute to associated risk factors such as COPD, diabetes, lung cancer, ischaemic heart disease, stroke, and other related cardiovascular and respiratory diseases. The economic valuation from these impacts on healthcare and welfare costs and productivity losses are also calculated.

To assess the full impact of coal plants in South Korea, we calculate the cumulative costs of dependence on these plants over time. The annual health impacts results are adjusted by age group-specific changes in population and all-cause mortality, based on historical data and projections in UNPD World Population Prospects 2019 (medium variant). Additionally, economic costs are adjusted by changes in per capita GDP (PPP). Up to 2019, the data are from the World Bank Databank, and future projections from OECD GDP long-term forecasts. The forecasts and historical data until 1989 include GDP in constant prices but without PPP adjustment, so growth rates in PPP adjusted GDP are assumed equal to the growth rates of real GDP. Past and future costs are discounted to 2019 value at 4%/year, as recommended by e.g. Hurley et al. (2005).

Table 1: Coal-fired Power plants in South Korea included in the modelling

Status	Power Plant	Units	Total Capacity (MW)	Province	Parent Company	Expected Year of Retirement or Conversion[3]
Operating	**Boryeong**	**8**	4000	Chungcheongnam-do	KEPCO	U1&2: 2021 U5&6: 2025
	Bukpyeong	**2**	1190	Gangwon - do	GS E&R	2047
	Dangjin	**10**	6040	Chungcheongnam-do	KEPCO	U1&2: 2029* U3&4: 2030* U5-10: 2035 to 2045
	Donghae	**2**	400	Gangwon - do	KEPCO	2029
	Hadong	**8**	4000	Gyeongsangnam-do	KEPCO	2026 - 2031
	Honam	**2**	500	Jeollabuk-do	KEPCO	2021
	Samcheok Green	**2**	2044	Gangwon - do	KEPCO	2047
	Samcheonpo	**6**	2120	Gyeongsangnam-do	KEPCO	U1&2: 2021 U3 & 4: 2023 U5 & 6: 2028
	Shin Boryeong	**2**	2000	Chungcheongnam-do	KEPCO	2047

[3] Approximately 13GW of coal plants will be switched to run on liquified natural gas. Plants that are expected to be converted into gas-fired power plants are denoted with a ***** in Table 1.

	Taean	**10**	6400	Chungcheongnam-do	KEPCO	U1& 2: 2025 U3&4: 2032* U5-10: 2035 to 2047
	Yeongheung	**6**	5080	Incheon	KEPCO	U1&2: 2034 U3-6: 2038 to 2044
	Yeosu	**2**	679	Jeollabuk-do	KEPCO	2046
Under Construction	**Gangneung Anin**	**2**	2080	Gangwon - do	Samsung C&T	2053
	Goseong Hi	**2**	2080	Gyeongsangnam-do	SK E&C	2051
	Samcheok Blue	**2**	2100	Gangwon - do	POSCO	2054
	Shin Seocheon	**1**	1000	Chungcheongnam-do	KEPCO	2051

SOURCE: Global Coal Plant Tracker, Argus Media, South Korean Ministry of Energy

Note: If retirement year is not scheduled, the average 30-year operating life of coal plants is assumed.

RESULTS

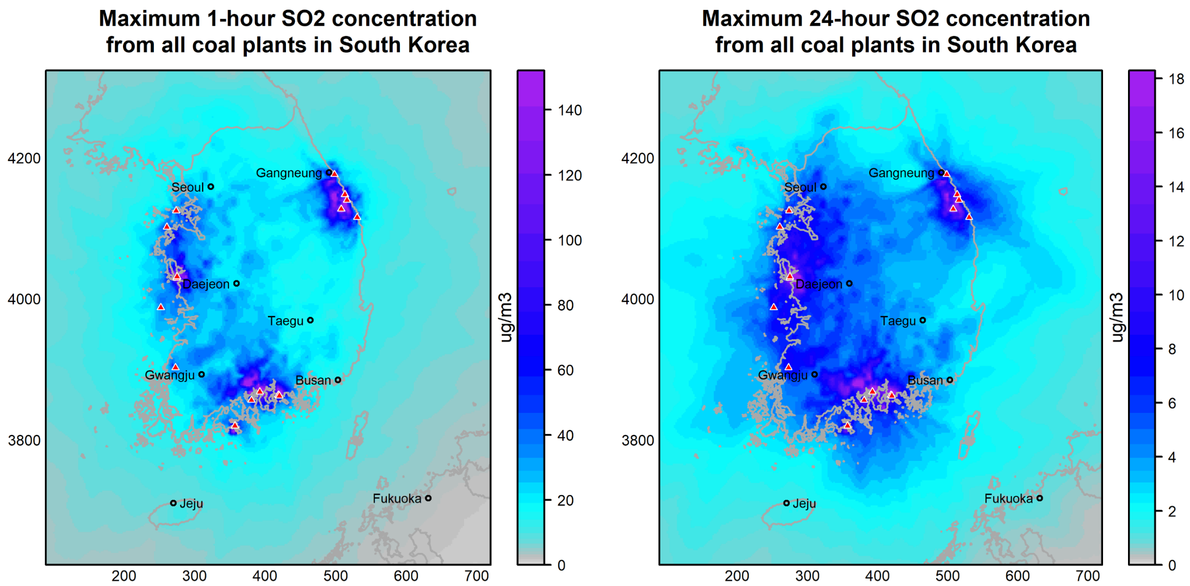
Emissions Load & Air Quality

The 12 operating coal-based power plants listed in Table 1 are estimated to emit 45.4 kilotons (kt) of SO2, 48.1 kt of NOx, and 3.0 kt of particulate matter (PM) pollution every year. With the 4 plants under construction, the annual emissions load increases to 55.3 kt of SO2, 56.5 kt of NOx, and 4.7 kt PM. Existing and projected pollution contribute significantly to outdoor air quality in South Korea and in surrounding areas.

Based on the results of the CALPUFF modelling, pollution from the coal-fired plants that exceeds maximum 1-hour concentrations of NO2 above the 200 μg/m^3 threshold affects 5,800 people in an area of 34 km^2. Maximum 1-hour concentrations for SO2 have an even greater effect with 140km^2 above the recommended 211.267 μg/m^3 threshold. Exposure to SO_2 exceedances is estimated at 23,000 people. Furthermore, the maximum 24-hours concentration of SO_2 would impact over 68,000 people.

Figure 2 visualized the impacts of this maximum hourly (1-hr and 24-hr) concentrations of SO2, NO2 and PM2.5 from the 67 modeled power plant units. In Figure 3, the annual mean concentrations of the same pollutants are presented. Both sets of figures show that while there are 3 major clusters of pollution in the country, emissions for all the pollutants travel across the country and even before its borders. As a result, pollution from the plants have impacts on air quality and the environment, and thus, peoples' health in areas far away from the original source.

Figure 2: Maximum 1-hour and 24-hour concentrations of SO2, NO2 and PM2.5



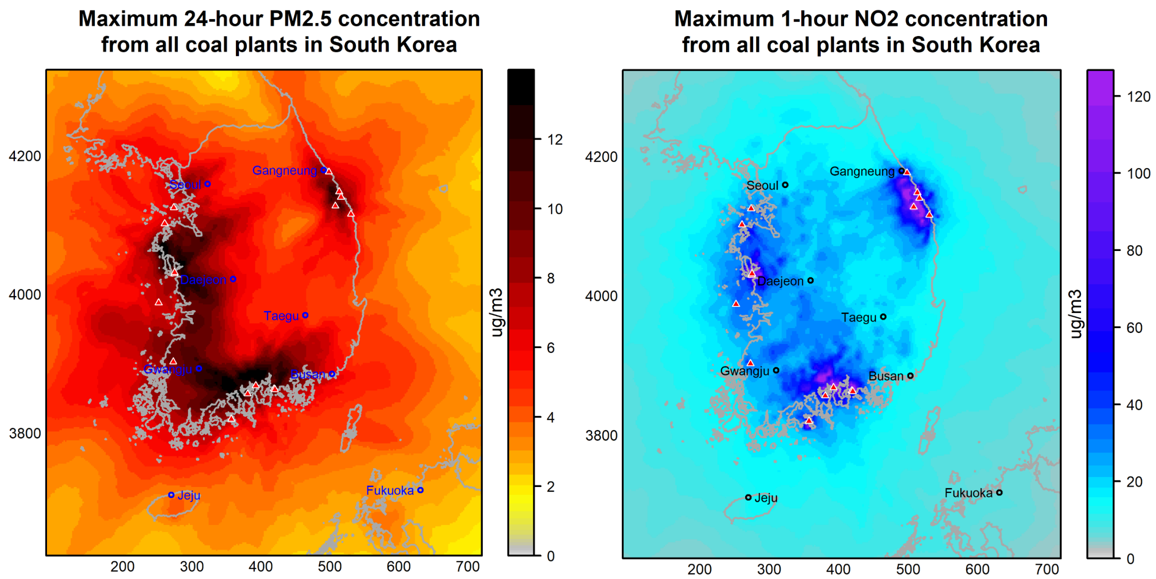
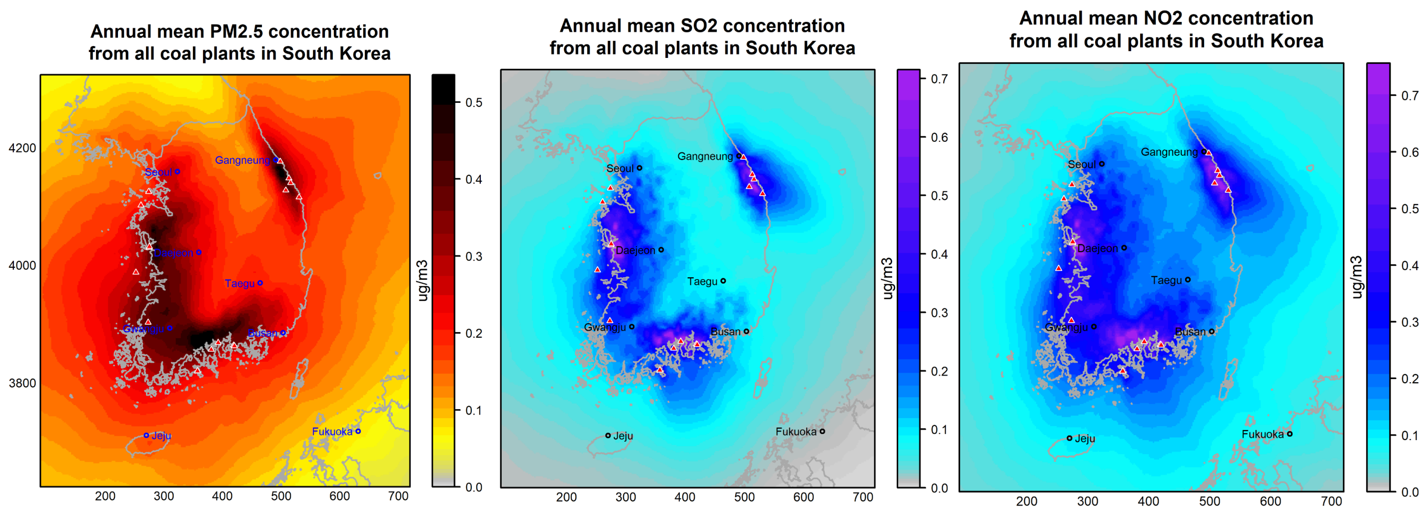


Figure 3: Annual Mean Concentrations from the modelled power plants

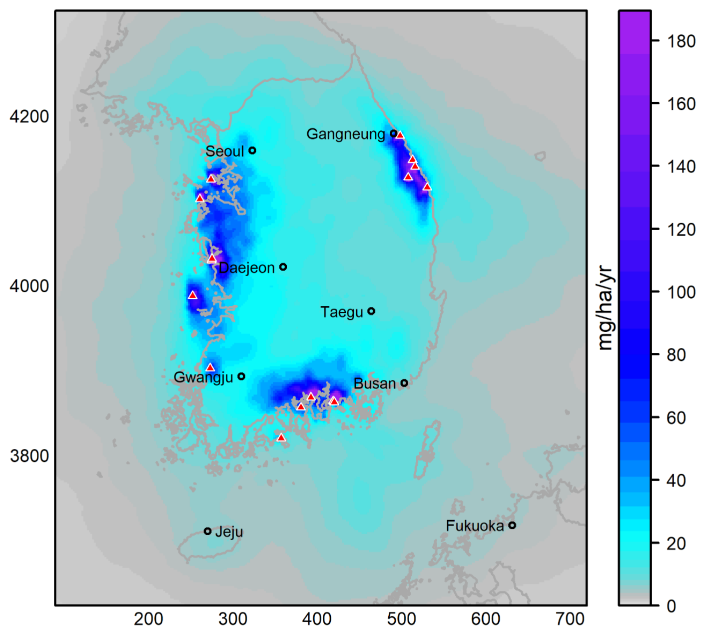


Toxic Deposition

In addition to SO_2, NOx and PM pollution, coal plants emit other toxic materials such as mercury and fly ash, which are deposited into the surrounding environment. Annual total mercury deposition emitted by the CFPPs is approximately 600 kg every year; half is deposited into land and freshwater ecosystems. An estimated 135 kg are deposited in cropland, where the absorption of errant mercury could affect agriculture. Studies show that rice paddies — a major source of food and agriculture in the country — can convert deposited inorganic mercury into methylmercury, which is easily taken up by the rice plant (see e.g. Zhang et al. 2010). The deposition of mercury has a dual impact on water bodies — direct deposition occurs when particles fall into water and accumulation happens when mercury deposited on land is washed downstream by rain and runoff into streams, rivers, lakes, wetlands, estuaries and oceans (UNEP 2018). The latter is not accounted for in this research; it is likely that total mercury levels are higher than the rates determined by air deposition alone.

Mercury deposition rates as low as 125mg/ha/year can lead to accumulation of unsafe levels of mercury in fish (Swain et al. 1992). Exceedance of such mercury levels are estimated over 2,700 km^2 of the modelling domain, affecting 376,000 people.

Figure 4: Annual Total Mercury Deposition from modelled coal plants



Additionally, an estimated 1,200 tons of fly ash containing toxic and radioactive heavy metals are also emitted from coal plants into land and freshwater ecosystems every year. These emissions do not include intentional discharges or possible leakage or accidental discharge from coal ash ponds, coal ash landfills, coal storage and other sources. Such episodes are difficult to project, but could add significantly to the heavy metal load into the environment.

When SO2 reacts with atmospheric chemicals, it forms another secondary compound known as acid deposition. An estimated 27,100 tons is released over the country's land and freshwater ecosystems per year. These compounds can be carried over great distances and deposited in wet form as rain or fog, or can simply settle out of the air as dy particles or gases (dry deposition). Approximately 90% of acid deposition estimated occurs over cropland and forests, which could deplete soils of essential nutrients. Acidic particles can also contribute to the corrosion of metals and to the deterioration of buildings, infrastructure, and other structures of cultural significance, resulting in depreciation of the value of these objects to society.

Health Impacts

The authors estimate that the operational and planned coal power plants in the study result in approximately 720 premature deaths across the country every year. The cost of these health impacts on the economy is estimated at USD 1.03 billion (KRW 1.2 trillion) every year. Majority of these impacts are from the currently operating fleet; although more than 60 premature deaths and USD 90 million could be avoided annually if the 7 GW of planned projects are not operationalized.

Table 2: Premature deaths within South Korea from coal power air pollution in 2019, by cause

Pollutant	Causes	Best estimate	Low estimate	High estimate
NO_2	all causes	281.5	137.2	433.3
$PM_{2.5}$	chronic obstructive pulmonary disease	22.0	7.9	41.0
	diabetes	4.0	1.2	8.0
	ischaemic heart disease	54.0	39.4	70.1
	lower respiratory infections	81.5	22.0	151.6
	lower respiratory infections in children	0.05	0.03	0.07
	lung cancer	57.2	27.8	95.1
	stroke	58.0	22.4	109.7
SO_2	all causes	74.8	50.7	100.5
total cases of premature deaths, annually		**716.0**	**461.4**	**987.3**

Table 3: Annual health impacts and economic cost (in USD million) within South Korea from coal power air pollution in 2019

Cause	Number of cases in South Korea			Cost in South Korea, in USD million		
	Best estimate	Low estimate	High estimate	Best estimate	Low estimate	High estimate
new cases of asthma in children	229.3	49.6	519.9	2.54	0.64	5.47
asthma emergency room visits	366.5	227.3	504.4	0.18	0.11	0.25
preterm births	80.5	39.0	85.5	16.99	8.23	18.04
work absence (sick leave days)	284,293	241,850	326,450	48.23	41.03	55.38
years lived with disability	728	240.3	1471.4	45.11	14.89	91.17
years of lives lost	12,946	8,348.7	17,893.8	920.7	593.7	1,272.5
Total Economic Cost in South Korea, annually				**1,033.7 (658.6 - 1,442.7)** *in KRW billion: 1,204 (767 - 1,681)*		

Isolating the health impacts per plant, the highest impacts come from power plants with the highest capacities, namely the 6040 MW Dangjin power plant (210 premature deaths in and outside of South Korea, annually), 5080 MW Yeongheung (160), and the 6400 MW Taean (140) power plant.

Table 4: Estimated annual health outcomes both within and outside of South Korea in 2019, per power plant

	work absence (sick leave days)	new cases of asthma in children	premature deaths	asthma emergency room visits	Preterm Births
Boryeong	50,667 (43,103 - 58,181)	35.3 (7.6 - 79.9)	122.7 (78.8 - 171.2)	70.6 (43.6 - 97.4)	18.6 (9.0 - 19.7)
Bukpyeong	11,044 (9,395 - 12,682)	8.8 (1.9 - 19.9)	30.9 (19.8 - 43.2)	16.4 (10.1 - 22.6)	4.5 (2.2 - 4.8)
Dangjin	79,829 (67,911 - 91,667)	64.9 (14.0 - 146.7)	209.4 (132.9 - 293.8)	112.4 (69.3 - 155.0)	29.4 (14.3 - 31.3)
Donghae	6,218 (5,290 - 7,140)	1.4 (0.3 - 3.1)	12.1 (8.5 - 16.1)	9.0 (5.5 - 12.4)	2.4 (1.2 - 2.5)
Gangneung Anin	10,318 (8,777 - 11,848)	4.9 (1.1 - 11.0)	24.2 (16.2 - 33.3)	15.7 (9.6 - 21.6)	4.4 (2.1 - 4.7)
Goseong Hi	19,721 (16,777 - 22,646)	7.9 (1.7 - 17.9)	43.2 (29.4 - 58.3)	27.0 (16.7 - 37.3)	7.0 (3.4 - 7.4)
Hadong	52,717 (44,847 - 60,534)	29.1 (6.3 - 65.8)	125.1 (83.0 - 171.1)	72.0 (44.5 - 99.2)	18.3 (8.9 - 19.5)
Honam	14,532 (12,363 - 16,687)	7.5 (1.6 - 16.9)	33.3 (22.1 - 45.8)	20.2 (12.4 - 27.8)	5.5 (2.6 - 5.8)
Samcheok Green Power	5,235 (4,453 - 6,011)	5.4 (1.2 - 12.2)	16.3 (10.2 - 23.0)	7.7 (4.7 - 10.6)	2.1 (1.0 - 2.2)
Samcheok POS Power	11,192 (9,521 - 12,852)	4.7 (1.0 - 10.7)	25.2 (17.0 - 34.2)	16.4 (10.1 - 22.6)	4.4 (2.1 - 4.7)
Samcheonpo	35,245 (29,983 - 40,472)	23.5 (5.1 - 53.2)	89.7 (58.6 - 123.6)	48.3 (29.8 - 66.5)	12.4 (6.0 - 13.1)
Shin Boryeong	19,536 (16,619 - 22,433)	7.4 (1.6 - 16.8)	39.8 (26.8 - 54.2)	27.3 (16.8 - 37.6)	7.2 (3.5 - 7.6)
Shin Seocheon	9,977 (8,488 - 11,457)	4.1 (0.9 - 9.2)	20.5 (13.7 - 28.1)	14.0 (8.6 - 19.4)	3.9 (1.9 - 4.1)
Taean	61,066 (51,949 - 70,122)	37.5 (8.1 - 84.7)	141.2 (91.1 - 197.2)	86.5 (53.3 - 119.4)	23.7 (11.5 - 25.2)
Yeongheung	61,926 (52,681 - 71,109)	44.0 (9.5 - 99.6)	162.5 (104.9 - 226.0)	87.1 (53.8 - 120.2)	22.7 (11.0 - 24.1)
Yeosu	2,084 (1,773 - 2,393)	3.1 (0.7 - 7.0)	7.5 (4.5 - 10.8)	2.9 (1.8 - 4.0)	0.8 (0.4 - 0.8)

Transboundary Impacts

Over 45% of cases of premature deaths from coal air pollution are estimated in two areas: Gyeonggi-do (210 annually) and Seoul (120). Notably, Chungcheongnam-do has the highest capacity of installed plants but is the 5th most impacted province in premature deaths. This demonstrates that the impact from the power plants are not limited to areas or people in close proximity to the plants. Pollutants are able to travel large distances. Areas with greater population density also have a greeted number of people per km^2 that are exposed to elevated levels of pollution. Despite not having coal plants built in Seoul, Incheon, and Busan, they are the most populated areas in the country thus a greater number of people are exposed to the combined pollution from nearby coal power clusters.

Table 5: Estimated annual health outcomes from coal power air pollution in 2019, by province and arranged by highest number of estimated premature deaths

	work absence (sick leave days)	new cases of asthma in children	premature deaths	asthma emergency room visits	Preterm Births
Gyeonggi-do	82,995 (70,604 - 95,302)	67.4 (14.6 - 152.9)	210.3 (135.4 - 290.2)	107.0 (66.4 - 147.3)	23.5 (11.4 - 25.0)
Seoul	47,057 (40,032 - 54,035)	37.5 (8.1 - 84.9)	116.6 (75.0 - 160.8)	60.7 (37.6 - 83.5)	13.3 (6.5 - 14.2)
Gyeongsangnam-do	21,801 (18,546 - 25,034)	17.1 (3.7 - 38.8)	54.7 (35.4 - 75.3)	28.1 (17.4 - 38.7)	6.2 (3.0 - 6.6)
Incheon	15,345 (13,054 - 17,621)	12.2 (2.6 - 27.6)	39.0 (25.2 - 53.8)	19.8 (12.3 - 27.2)	4.3 (2.1 - 4.6)
Jeollanam-do	15,010 (12,770 - 17,236)	13.3 (2.9 - 30.1)	39.8 (25.4 - 55.0)	19.4 (12.0 - 26.6)	4.3 (2.1 - 4.5)
Chungcheongnam-do	14,523 (12,355 - 16,676)	13.5 (2.9 - 30.7)	39.9 (25.4 - 55.3)	18.7 (11.6 - 25.8)	4.1 (2.0 - 4.4)
Busan	14,596 (12,417 - 16,760)	9.4 (2.0 - 21.3)	33.3 (22.0 - 45.5)	18.8 (11.7 - 25.9)	4.1 (2.0 - 4.4)
Jeollabuk-do	12,636 (10,750 - 14,510)	10.1 (2.2 - 22.9)	31.6 (20.4 - 43.5)	16.3 (10.1 - 22.4)	3.6 (1.7 - 3.8)
Gyeongsangbuk-do	12,356 (10,511 - 14,188)	10.2 (2.2 - 23.0)	31.1 (20.0 - 42.8)	15.9 (9.9 - 21.9)	3.5 (1.7 - 3.7)
Gwangju	10,520 (8,949 - 12,080)	7.6 (1.7 - 17.3)	24.7 (16.0 - 33.9)	13.6 (8.4 - 18.7)	3.0 (1.4 - 3.2)
Chungcheongbuk-do	8,497 (7,228 - 9,757)	7.5 (1.6 - 16.9)	22.1 (14.1 - 30.6)	11.0 (6.8 - 15.1)	2.4 (1.2 - 2.6)
Daegu	8,110 (6,899 - 9,313)	6.7 (1.5 - 15.3)	20.1 (12.9 - 27.8)	10.5 (6.5 - 14.4)	2.3 (1.1 - 2.4)
Daejeon	7,937 (6,752 - 9,115)	6.6 (1.4 - 15.0)	20.2 (13.0 - 28.0)	10.2 (6.3 - 14.1)	2.2 (1.1 - 2.4)
Gangwon-do	6,475 (5,509 - 7,436)	6.1 (1.3 - 13.9)	18.1 (11.5 - 25.0)	8.3 (5.2 - 11.5)	1.8 (0.9 - 1.9)
Ulsan	4,112 (3,498 - 4,721)	2.7 (0.6 - 6.2)	9.4 (6.2 - 12.9)	5.3 (3.3 - 7.3)	1.2 (0.6 - 1.2)
Jeju	1,815 (1,544 - 2,085)	0.9 (0.2 - 2.1)	3.7 (2.5 - 5.0)	2.3 (1.5 - 3.2)	0.5 (0.2 - 0.5)
Sejong	508 (433 - 584)	0.5 (0.1 - 1.0)	1.3 (0.9 - 1.9)	0.7 (0.4 - 0.9)	0.1 (0.1 - 0.2)

Table 6: Estimated economic cost of coal power air pollution in 2019, by province

Province	Cost, KRW million	Cost, USD million	Cost per capita, USD
Gyeonggi-do	353,208 (224,919 - 492,719)	303.1 (193 - 422.8)	496
Seoul	196,190 (124,959 - 273,254)	168.4 (107.2 - 234.5)	400
Gyeongsangnam-do	92,315 (58,994 - 129,001)	79.2 (50.6 - 110.7)	368
Jeollanam-do	66,568 (42,139 - 93,285)	57.1 (36.2 - 80)	352
Chungcheongnam-do	66,399 (41,840 - 93,028)	57 (35.9 - 79.8)	320
Incheon	65,451 (41,760 - 91,080)	56.2 (35.8 - 78.2)	288
Busan	56,926 (36,900 - 78,972)	48.8 (31.7 - 67.8)	240
Jeollabuk-do	53,111 (33,862 - 74,071)	45.6 (29.1 - 63.6)	240
Gyeongsangbuk-do	52,488 (33,421 - 73,614)	45 (28.7 - 63.2)	224
Gwangju	41,800 (26,831 - 58,105)	35.9 (23 - 49.9)	192
Chungcheongbuk-do	37,053 (23,455 - 51,930)	31.8 (20.1 - 44.6)	160
Daegu	34,013 (21,583 - 47,675)	29.2 (18.5 - 40.9)	128
Daejeon	33,975 (21,602 - 47,472)	29.2 (18.5 - 40.7)	80
Gangwon-do	30,254 (19,067 - 42,641)	26 (16.4 - 36.6)	80
Ulsan	16,117 (10,423 - 22,435)	13.8 (8.9 - 19.3)	48
Jeju	6,417 (4,269 - 8,837)	5.5 (3.7 - 7.6)	32
Sejong	2,251 (1,424 - 3,154)	1.9 (1.2 - 2.7)	16

The health and economic impacts of air pollution from coal plants also extends to neighboring countries. A total of 390 premature deaths — or 35% of total premature deaths — is estimated to occur in North Korea, China, Russia, and Japan. The total estimated economic cost of coal-fired power plants outside of Korea is USD 270 million (KRW 311 billion) per year.

Table 7: Estimated annual health impacts from coal power air pollution in 2019, in areas outside of South Korea

Cause	Number of cases outside South Korea			Cost outside South Korea (in USD Million)		
	Best estimate	Low estimate	High estimate	Best estimate	Low estimate	High estimate
new cases of asthma in children	60.1	13.0	134.7	-	-	-
number of children suffering from asthma due to pollution exposure (increased prevalence)	259.4	64.1	559.3	0.36	0.09	0.76
asthma emergency room visits	266.8	163.5	369.1	0.05	0.03	0.06
preterm births	86.6	41.9	92.0	5.24	2.54	5.56
premature deaths	387.6	255.9	542.5	-	-	-
work absence (sick leave days)	167,015	142,079	191,784	11.26	9.58	12.94
years lived with disability	483.3	157.5	975.0	14.65	4.46	30.24
years of life lost	7,243.0	4,671.1	10,395.6	0	159.19	319.42
Total Economic Cost outside of South Korea, annually				**266.96 (175.88 - 368.98)** *in KRW billion: 311.1 (204.9 - 430.0)*		

Cumulative Cost of Coal Dependence, Past & Future

As generation from coal plants has increased, so has the impact of air pollution from the plants. Emissions from plants currently in operation have cumulatively caused approximately 9,500 premature deaths within South Korea until the end of 2020. Accounting for projected changes in population, health profile and GDP and the scheduled retirements, the estimated number of additional premature deaths between the start of 2021 and 2054 amounts to 16,000 premature deaths.

Of the modelled plants, emissions from the 10-unit Dangjin power plant result in the highest health impacts and economic costs over its operating life, followed by the Yeongheung, Taean, and Boryeong power plants. Combined, they account for over 60% of past cases of premature deaths; yet, only 24 of the 34 units that compose these 4 power plants are included in the Ministry's 2030 list of units for closure. The remaining units will account for almost 70% of projected future health impacts.

Impacts and the associated costs are expected to peak in 2024, when the last of the plants under construction is scheduled to come online and many of the smaller and older units are taken offline.

Figure 5: Estimated number of premature deaths in South Korea from coal power air pollution over time. Cumulative numbers represent best estimates and 95%-confidence interval

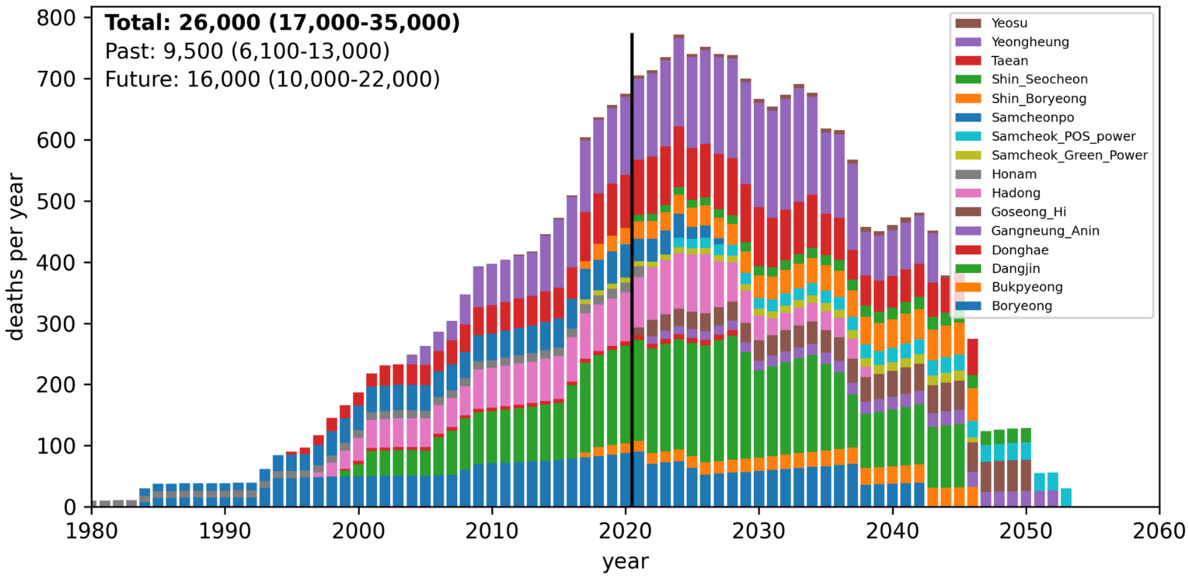


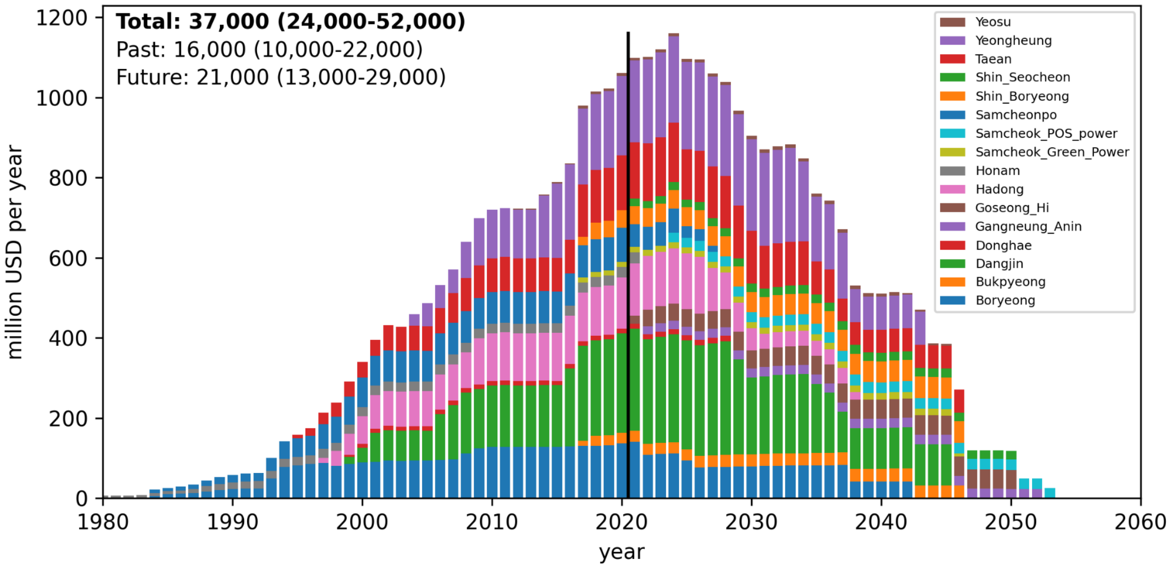
Table 8: Cumulative health impacts and related costs within South Korea from air pollution from coal-fired power plants over their (scheduled) operation time

Health outcome	Number of cases in South Korea			Cost (USD million) in South Korea		
	Best estimate	Low estimate	High estimate	Best estimate	Low estimate	High estimate
new cases of asthma in children	6,987	1,509	15,841	-	-	-
asthma emergency room visits	11,219	6,934	15,465	5	3	8
preterm births	2,715	1,314	2,883	608	294	646
work absence (sick leave days)	8,053,685	6,851,347	9,247,969	1,445	1,229	1,659
years lived with disability	26,300	8,683	53,169	1,632	538	3,299
years of lives lost	464,824	300,115	642,103	33,272	21,462	45,982

From 1983 through 2020, the estimated economic cost due to air pollution from coal power is USD 16 billion. Between 2021 and 2054, the country is expected to incur an additional USD 21 billion as a result of continued dependence on coal.

Air pollution from Dangjin, Yeongheung, Taean, and Boryeong power plants contribute almost 68% of the total economic cost over time. These are borne most heavily in the highly populous areas of Gyeonggi-do and Seoul, followed by the provinces of Gyeongsangnam-do and Jeollanam-do, where most of the plants are located. In all of these areas, more than 60% of these negative externalities calculated are expected to occur in the future, as projected increases in both South Korea's population and GDP mean that more people are likely to be exposed to air pollution from the plants as the economic costs and losses from the associated health impacts increase.

Figure 6: Economic cost (in USD million) in South Korea from air pollution of coal-fired power plants over their scheduled operation time



Recommendations

The South Korean government's coal phaseout plan should be a key priority in the transition to a zero carbon economy. Our results show that the benefits of tackling emissions from coal-fired power plants in South Korea are not only limited to meeting the Paris Agreement and national energy policy targets, but also improved air quality to a degree that would improve health and reduce associated costs.

Health impacts from historic coal use have already cost the country's population an estimated USD 16 billion (95%-confidence interval: USD 10 to 22 billion). Following the retirement schedule under the 9th Basic Plan for Electricity Supply and Demand 2020-2034, an additional 16,000 premature deaths are estimated to occur between 2021 and 2054, costing the country over USD 21 billion. An accelerated energy transition that prioritizes renewable energy could avoid the worst of these health impacts and costs.

It is important to note that these impacts do not account for improvements in emission control technologies over time; emissions loads based on the control technologies in the plants as of December 2020, were used. Emissions from nearly 2 GW of retired plants (all having operated for more than 30 years) are also not included in the estimates. Thus, the results for past and future cumulative costs are conservative estimates.

To do this, we recommend that investments in coal must be halted and a national plan for an accelerated coal phaseout should be established as soon as possible. Additional coal and retrofits will only delay phaseout efforts while continuing to impact the health and economy of the country. The population exposed to air pollution would benefit substantially from an accelerated decommissioning schedule. The plan should set clear targets for cancellation or fuel conversion of each of the 60 coal units, as well as the 7 new coal generation units planned to be added to the system over the next 5 years. This, alongside the prioritization of investments in renewables and energy efficiency in the power, industry and transport sectors, would also yield faster reductions in air pollution, improvements in healthcare spending, and the promotion of economic growth.

South Korea's efforts to transition its economy away from coal and protect the health of its citizens will require more ambitious and coordinated efforts across various sectors and between major stakeholders. To become a leader in the zero-carbon transition, detailed examination and analysis of how action and investments can provide co-benefits and returns. As this report shows, action in one sector — in this case, the power sector — could have outsized benefits for another, such as healthcare. Planning and investments from utilities, policymakers, investors, and other stakeholders should not run counter to climate commitments. Major coal owners like KEPCO, and financiers, like the NPS, should cease direct project and dedicated financing, insurance coverage, and other specialized financial support like advisory mandates and direct investments to any type of coal-related projects.

References

Donkelaar van, A., Martin, R.V., Brauer, M., Hsu, N.C, Khan, R. A., Levy, R.C., Lyapustin, A., Sayer, A. M. & Winker, D.M 2016. Global Estimates of Fine Particulate Matter using a Combined Geophysical-Statistical Method with Information from Satellites, Models,and Monitors, Environ. Sci. Technol.50(7):3762-3772. https://doi.org/10.1021/acs.est.5b05833

European Space Agency (ESA) 2018. Land Cover Maps –v2.0.7. http://maps.elie.ucl.ac.be/CCI/viewer/download.ph

Eunseo, K. 2021. "2050 탄소중립 지지" 국내 금융기관 112곳 '기후금융' 선언 (09 March 2021). https://www.hankyung.com/society/article/202103097238i

Farr, T.G., Rosen, P.A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Oskin, M., Burbank, D. & Alsdorf, D. 2007. The Shuttle Radar Topography Mission. Reviews of Geophysics 4(2), RG2004. https://doi.org/10.1029/2005RG000183

Gabbatis, J. 2020. The Carbon Brief Profile: South Korea. https://www.carbonbrief.org/the-carbon-brief-profile-south-korea

Hoek, G., Krishnan, R.M., Beelen, R. et al. 2013. Long-term air pollution exposure and cardio- respiratory mortality: a review. Environ Health 12, 43 (2013). https://doi.org/10.1186/1476-069X-12-43

Hurley, F., Hunt, A., Cowie, H., Holland, M., Miller, B., Pye, S. & Watkiss, P. 2005. Methodology for the Cost-Benefit analysis for CAFE: Volume 2: Health Impact Assessment. AEA Technology Environment, UK. https://ec.europa.eu/environment/archives/cafe/pdf/cba_methodology_vol2.pdf

IQAir 2020. 2019 World Air Quality Report. https://www.iqair.com/blog/press-releases/report-over-90-percent-of-global-population-breathes-dangerously-polluted-air

Ji-hyoung, S. 2021. Korean investors' $16.8b coal exposure highlights call for climate action. The Korea Herald (25 Feb 2021). http://www.koreaherald.com/view.php?ud=20210225000765

Koplitz, S.N., Jacob, D.J., Sulprizio, M.P., Myllyvirta, L. & Reid, C. 2017. Burden of Disease from Rising Coal-Fired Power Plant Emissions inSoutheast Asia. EnvironmentalScience & Technology 51(3): 1467-1476. https://doi.org/10.1021/acs.est.6b03731

KoSIf, 양이원영 더불어민주당 의원, 그린피스. 한국 석탄금융 12년그 중독의 기록. 2020. https://www.greenpeace.org/korea/report/15492/report-2020-coal-finance/

Kim, S. E., Xie, Y., Dai, H., Fujimori, S., Hijioka, Y., Honda, Y., Hashizume, M., Masui, T., Hasegawa, T., Xu, X., Kan, Y. & Kim, H. 2020. Air quality co-benefits from climate mitigation for human health in South Korea. Environment International, Volume 136. 2020. ISSN 0160-4120. https://doi.org/10.1016/j.envint.2020.105507

Krewski, D. et al. 2009. Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. HEI Research Report 140. Health Effects Institute, Boston, MA. http://dx.doi.org/10.1021/acs. est.6b03731

Larkin, A., Geddes, J.A., Martin, R.V., Xiao, Q., Liu, Y., Marshall, J.D., Brauer, M. & Hystad, P. 2017. Global Land Use Regression Model for Nitrogen Dioxide Air Pollution. Environmental Science & Technology 51(12):6957-6964. https://doi.org/10.1021/acs.est.7b01148

Lee, E. & Horslen, J. 2020. S Korea to convert half of existing coal fleet to gas. Argus Media. 11 May 2020. www.argusmedia.com/en/news/2104174-s-korea-to-convert-half-of-existing-coal-fleet-to-gas

Lee, S.J., Seo, Y.C., Jang, H.N., Park, K.S., Baek, J.I., An, H.S., Song, K.S., 2006. Speciation and mass distribution of mercury in a bituminous coal-fired power plant. Atmospheric Environment 40:2215–2224. https://doi.org/10.1016/j.atmosenv.2005.12.01

Ministry of Environment of Korea 2019. The Clean Air Conservation Act (accessed 18 Sep 2019) http://www.law.go.kr/LSW// lsInfoP.do?lsiSeq=209973&efYd=20190716#AJAX

Ministry of Environment of Korea 2021. Joint update of the environmental authorities of Korea and China on their fine dust response. Press Release (10 Feb 2021). http://eng.me.go.kr/eng/web/board/read.do?pagerOffset=0&maxPageItems=10&maxIndexPages=10&searchKey=&searchValue=&menuId=461&orgCd=&boardId=1432680&boardMasterId=522&boardCategoryId=&decorator=

Myllyvirta, L. 2020. Quantifying the Economic Costs of Air Pollution from Fossil Fuels.Centre for Research on Energy and Clean Air. https://energyandcleanair.org/wp/wp-content/uploads/2020/02/Cost-of-fossil-fuels-briefing.pd

National Law Information Center Korea 2021. Clean Air Conservation Act. 국가법령정보센터 | 법령 > 본문 - 대기환경보전법 시행규칙 (law.go.kr)

Swain, E.B., Engstrom, D.R., Brigham, M.E., Henning, T.A., Brezonki, P.L. 1992. Increasing Rates of Atmospheric Mercury Deposition in Midcontinental North America. Science 257(5071):784-787. https://doi.org/10.1126/science.257.5071.784

The Government of Republic of Korea 2020. 2050 Carbon Neutral Strategy of the Republic of Korea Towards a Sustainable and Green Society. https://unfccc.int/sites/default/files/resource/LTS1_RKorea.pdf

The Republic of Korea Office of the President 2020. Remarks by President Moon Jae-in for First International Day of Clean Air for blue skies. Briefing, Speeches and Remarks (07 Sept 2020). https://english1.president.go.kr/BriefingSpeeches/Speeches/871

UNEP 2018. Global Mercury Assessment 2018. UN Environment Programme, Chemicals and Health Branch Geneva, Switzerland. https://www.unenvironment.org/resources/publication/global-mercury-assessment-2018

White, E., Jung-a, S., Mooney, A. & Smyth, J. 2020. Global investors warn South Korea's Kepco over carbon emissions. Financial Times (24 Feb 2020). https://www.ft.com/content/2b5a7306-4f16-11ea-95a0-43d18ec715f5

Zhang, H., Feng, X., Larssen, T., Qiu, G. & Vogt, R.D. 2010. In Inland China, Rice, Rather than Fish, Is the Major Pathway for Methylmercury Exposure. Environmental HealthPerspectives. 118(9): 1183–1188. https://dx.doi.org/10.1289%2Fehp.100191

Appendix 1: Methods & Materials

This study follows CREA's impact pathway approach (IPA) to quantify the health impacts of coal power generation. It is carried out by (1) developing a plant-by-plant inventory of emissions; (2) estimating pollution dispersion from CFPPs through atmospheric modeling; (3) quantifying air pollution health impacts resulting from changes in ambient concentration; and (4) valuing impacts in monetary terms using a cost of illness method. The analysis was carried out in the R data analysis software, in a global spatial grid with 1x1km resolution, with health impacts calculated for each grid cell. All datasets were aggregated or interpolated to this resolution as required.

Emissions

A plant-by-plant emissions inventory was used as input data to the CALPUFF model, accounting for plant-specific technology, location, and capacity for every operating coal plant in the country (see Appendix 2). Information on combustion and emission control technology, coal type used, stack height and diameter, as well as flue gas release velocity and temperature were used to calculate emissions load and account for plume release height and thermal rise of pollutants.

If a plant's emissions values were lacking or unavailable, it was generalized using average values for projects with similar capacity and combustion technology. We assumed that such plants were in compliance with the country's emissions standards and operating emission controls technology at full capacity. Information on installed emission controls were also collected from these primary documents, as well as the S&P (2020) World Electric Power Plants database.

Stack height as well as flue gas exit velocity and temperature were imputed from available data following the same approach. When missing, the stack diameter was calculated based on estimated total flue gas volume flow and velocity. If unavailable, thermal efficiencies of 37%, 41% and 43% were assumed for subcritical, supercritical and ultra-supercritical plants, respectively, in line with industry standards.

Separately, mercury emissions were projected using the formula: EHg = CC x MC x (1 - CE), where CC is the coal consumption mass rate of the plant, MC is the mercury content of the coal, and CE is the capture efficiency. For toxic deposition from main boilers of the power plants, 30% of emitted fly ash was assumed to be PM2.5, and 37.5% PM10, in line with the U.S. EPA (1998) AP-42 default value for electrostatic precipitators (ESP). Mercury deposition was modeled for three different types of mercury: elemental, reactive gaseous and particle-bound mercury, with the speciation between the three types calculated based on Lee et al. (2006).

Atmospheric Modeling

The CALPUFF modeling system was used to predict the contribution of CFPPs to ambient air pollutant concentrations at every modeled "receptor" location. These results were processed to extract the annual mean, 24-hour maximum and 1-hour maximum pollutant concentrations for 2019. CALPUFF is the most widely used, industry standard emission dispersion model for long-range air quality impacts of point sources. It is able to model the formation of secondary sulfate and nitrate particles from coal power SO2 and NOx emissions, and able to model long-range transport. These two mechanisms are responsible for more than 90% of the population exposure to PM2.5 and of the health impacts of CFPP emissions; their exclusion would mean omitting the majority of the health impacts. By accounting for transport, chemical transformation and deposition of pollutants, it provides short and long-range impacts caused by coal plant emissions.

Meteorological data used for the simulations were generated with the WRF model, on a 9x9km grid. Land-use data were obtained from the European Space Agency (2018) and terrain elevation data were obtained from NASA Shuttle Radar Topography Mission (SRTM) high resolution datasets (Farr et al. 2007).

Deposition results were differentiated by land-use type using the European Space Agency global land-use map for the year 2015 at a 300 m resolution (ESA 2018). Land-use codes 10-30 were mapped as cropland; codes 50-100 were mapped as forest and code 170 as mangrove. Monthly average backgrounds for NH3, O3 and H2O2 concentrations were also obtained from the Geos-Chem model results (Koplitz et al. 2017) and were inputted into the CALPUFF chemistry module (ISORROPIA/RIVAD).

Health Impact Assessment & Economic Valuation

The health impact assessment methodology and the economic valuation is adapted from CREA's "Quantifying the Economic Costs of Air Pollution from Fossil Fuels" (Myllyvirta 2020). Data on total population and population age structure, as well as all mortality results, baseline death rates and years of life lost for South Korea were taken from the GBD project 2019 (IHME 2020). The baseline concentrations of PM2.5 and NO2 were taken from van Donkelaar et al. (2016) and Larkin et al. (2017), respectively.

The health impacts are adjusted by age group-specific changes in population and all-cause mortality, based on historical data and projections in UNPD World Population Prospects 2019 (medium variant). Additionally, economic costs are adjusted by changes in per capita GDP (PPP). Up to 2019, the data are taken from the World Bank Databank, and future projections from OECD GDP long-term forecasts. The forecasts and historical data until 1989 include GDP in constant prices but without PPP adjustment, so growth rates in PPP adjusted GDP are assumed equal to the growth rates of real GDP. Past and future costs are discounted to 2019 value at 4%/year, as recommended by e.g. Hurley et al. (2005).

Table A1.1: Input parameters and data used to estimate economic impacts

Effect	Valuation	Currency	Unit	Year	Source	Adjustment	Reference Income level	Elasticity
New asthma cases	3,914	USD	case	2010	Brandt et al 2012	GDP PPP	California	1
Asthma emergency room visits	844	USD	visit	2010	Brandt et al 2012	GDP PPP	California	1
Preterm birth	321,989	USD	birth	2010	Trasande et al 2016	GDP PPP	US	1
Disability	62,800	GBP	years lived with	2018	Birchby 2019	GNI PPP	UK	1

			disability					
Premature deaths	56,000	EUR	lost life year	2005	EEA 2014	GNI PPP	EU	0.9
Work absence	130	EUR	work day	2005	EEA 2014	GDP PPP	EU	1

Table A1.2: Input parameters and data used to estimate economic costs of health impacts converted to South Korean Won (KRW)

Outcome	World Avg GDP, 2011 USD	Valuation in South Korea, 2011 USD	Valuation in South Korea, 2019 USD	Valuation in South Korea, 2019 KRW
preterm births	105,725	283,419.47	211,010.67	245,902,871.97
work absence (sick leave days)	85	227.86	169.65	197,699.16
years of life lost	39,324	95,517.83	71,114.67	82,874,018.24
years lived with disability	31,047	83,228.41	61,964.99	72,211,364.07
number of children suffering from asthma due to pollution exposure *(increased prevalence)*	1,168	3,131.08	2,331.15	2,716,619.10
asthma emergency room visits	252	675.54	502.95	586,119.87

Appendix 2: Stack Properties and Emissions Data

The following data was used to calculate the emissions limits for each individual all coal-fired power plants in South Korea. The emissions limits found in this table were subsequently used as input data in the CALPUFF Modeling.

Table A2: Coordinates, stack properties and emissions limits of South Korean coal-fired power plants

	Coordinates		Stack Properties				Emissions Limits (tpa)			
	Lat	Long	Stack height, meter	Diameter, meter	Exit Temp, Celsius	Flue Gas Velocity	SO_2	NOx	PM	Hg (kgpa)
Yeosu Unit 1	34.840	127.691	150	4.8	91	27.171	128	392	14	17.043
Yeosu Unit 2	34.840	127.691	150	4.8	91	21.564	76	427	11	16.837
Yeongheung Unit 1	37.242	126.446	200	6.6	90	18.064	1239	937	60	31.823
Yeongheung Unit 2	37.242	126.446	200	6.6	90	18.064	1363	975	52	35.016
Yeongheung Unit 3	37.242	126.446	198	6.3	90	20.403	888	536	16	36.365
Yeongheung Unit 4	37.242	126.446	198	6.3	90	20.403	819	513	25	33.82
Yeongheung Unit 5	37.242	126.446	200	6.9	95.3	17.437	497	450	22	38.214
Yeongheung Unit 6	37.242	126.446	200	6.9	95.3	17.437	507	463	20	38.08
Taean Unit 1	36.000	126.245	150	8.83	79.83	8.944	319.92	560.42	52.69	16.69
Taean Unit 2	36.000	126.244	150	8.83	77.87	8.944	271.61	340.95	31.486	19.148
Taean Unit 3	35.999	126.243	150	8.83	78.41	8.944	321.87	835.43	93.699	12.235
Taean Unit 4	35.9997	126.242	150	8.83	77.69	8.944	691.14	710.3	99.03	17.755
Taean Unit 5	35.999	126.2413	150	5.4	78.49	23.351	993.422	885.59	77.73	20.218
Taean Unit 6	35.999	126.2411	150	5.4	82.22	23.351	1353.26	1036.85	93.213	17.379
Taean Unit 7	35.9986	126.2396	150	5.4	95.87	27.653	451.33	566.51	20.404	19.614
Taean Unit 8	35.9986	126.2395	150	5.4	96.41	27.653	598.45	699.56	23.511	19.297
Taean Unit 9	35.9972	126.237	150	7.3	91	32.948	706.2	794.55	77.056	40.431
Taean Unit 10	35.9973	126.237	150	7.3	91	32.948	1010.87	815.97	53.422	30.069
Shin Boryeong Unit 1	36.384	126.485	150	7.5	90	16.75	1150	507	29	34.074
Shin Boryeong Unit 2	36.384	126.485	150	7.5	90	16.75	1005	763	45	32.209
Samcheonpo Unit 1	34.9117	128.109	200	5.3	119	37.531	687	1122	39	17.411
Samcheonpo Unit 2	34.9117	128.109	200	5.3	109	37.531	557	1178	57	17.673
Samcheonpo Unit 3	34.9117	128.109	200	5.3	95	37.531	1230	2035	75	26.33

Samcheonpo Unit 4	34.9117	128.109	200	5.3	100	37.531	1044	1302	71	20.59
Samcheonpo Unit 5	34.9117	128.109	200	5.3	139	24.154	645.077	520.78	118.14	22.308
Samcheonpo Unit 6	34.911	128.109	200	5.3	148	23.842	725.65	585.8	132.9	25.007
Samcheok Green Power Unit 1	37.186	129.34	90	8.8	90	15.053	595	1445	105	47.926
Samcheok Green Power Unit 2	37.184	129.34	90	8.8	90	15.053	330	1008	60	37.257
Honam Unit 1	34.511	127.440	150	7	90	6.566	681	862	17	11.410
Honam Unit 2	34.511	127.440	150	7	90	6.566	1379	1558	32	6.24076
Hadong Unit 1	34.95	127.82	150	9.3	83	7.359	1113	1094	50	18.924
Hadong Unit 2	34.95	127.82	150	9.3	83	6.628	1174	706	47	23.2721
Hadong Unit 3	34.951	127.82	150	9.3	83	6.613	1128	707	49	23.545
Hadong Unit 4	34.952	127.819	150	9.3	83	6.491	970	855	30	19.23
Hadong Unit 5	34.952	127.819	150	9.3	83	6.67	898	721	40	22.3634
Hadong Unit 6	34.953	127.819	150	9.3	83	6.769	819	1129	40	18.25
Hadong Unit 7	34.954	127.818	150	5.4	82	18.588	720	808	37	18.494
Hadong Unit 8	34.954	127.818	150	5.4	82	19.129	886	855	49	22.3
Donghae Unit 1	37.2907	129.085	150	4	154	16.154	770	262	7	24.283
Donghae Unit 2	37.2909	129.085	150	4	154	16.154	857	341	10	20.40
Dangjin Unit 1	37.0315	126.305	151	6.5	85	15.357	691	602	52	19.46
Dangjin Unit 2	37.0315	126.304	151	6.5	85	15.357	662	706	53	22.75
Dangjin Unit 3	37.0316	126.304	151	6.5	85	15.357	562	592	44	14.98
Dangjin Unit 4	37.0317	126.304	151	6.5	85	15.357	664	544	42	17.33
Dangjin Unit 5	37.0318	126.303	150	5.4	90	22.168	540	687	53	19.361
Dangjin Unit 6	37.0319	126.303	150	5.4	90	22.168	627	667	54	18.994
Dangjin Unit 7	37.032	126.303	150	5.4	90	22.168	393	464	42	17.11
Dangjin Unit 8	37.032	126.302	150	5.4	90	22.168	397	431	47	16.676
Dangjin Unit 9	37.0323	126.302	200	7.4	91	25.651	796	829	22	27.6
Dangjin Unit 10	37.0324	126.302	200	7.4	91	25.651	1079	1058	27	29.64
Bukpyeong Unit 1	37.477	129.146	150	5.3	90	24.507	1212	1910	84	25.048
Bukpyeong Unit 2	37.477	129.146	150	5.3	90	24.507	1212	1910	84	25.225
Boryeong Unit 1	36.402	126.488	150	8.864	85	7.179	570	959	53	15.059
Boryeong Unit 2	36.402	126.489	150	8.864	85	7.179	470	1320	40	15.09
Boryeong Unit 3	36.402	126.49	150	8.788	90	8.767	515.7	416.312	94.45	15.097
Boryeong Unit 4	36.402	126.491	150	8.762	90	7.33	804	464	26	17.952
Boryeong Unit 5	36.402	126.492	150	8.788	90	7.287	1013	667	49	19.0115

Boryeong Unit 6	36.402	126.493	150	8.788	90	7.287	1146	689	34	21.4093
Boryeong Unit 7	36.402	126.494	150	5.4	90	17.204	235	312	43	20.032
Boryeong Unit 8	36.402	126.494	150	5.4	90	17.204	229	604	32	17.09
Shin Seocheon	35.239	126.502	150	7.4	90	21.004	1363.58	1159.12	237.62	45.717
Goseong Hi Unit 1	34.902	128.123	190	7.5	90	22.493	1499.98	1275.06	261.39	48.926
Goseong Hi Unit 2	34.902	128.123	190	7.5	90	22.493	1499.98	1275.06	261.39	48.926
Gangneung Anin Unit 1	37.734	128.978	102	7.6	101	21.931	1388.59	1120.98	254.305	52.069
Gangneung Anin Unit 2	37.734	128.978	102	7.6	101	21.9311	1388.59	1120.98	254.305	52.069
Samcheok Blue Power power Unit 1	37.407	129.177	250	7.4	90	22.286	1415.38	1203.14	246.643	43.735
Samcheok Blue Power power Unit 2	37.407	129.177	250	7.4	90	22.286	1415.38	1203.14	246.643	43.735

Appendix 3: Per-plant Results

Figure A3.1: Premature deaths in South Korea due to air pollution from coal-fired power plants over their operation time, by plant and unit

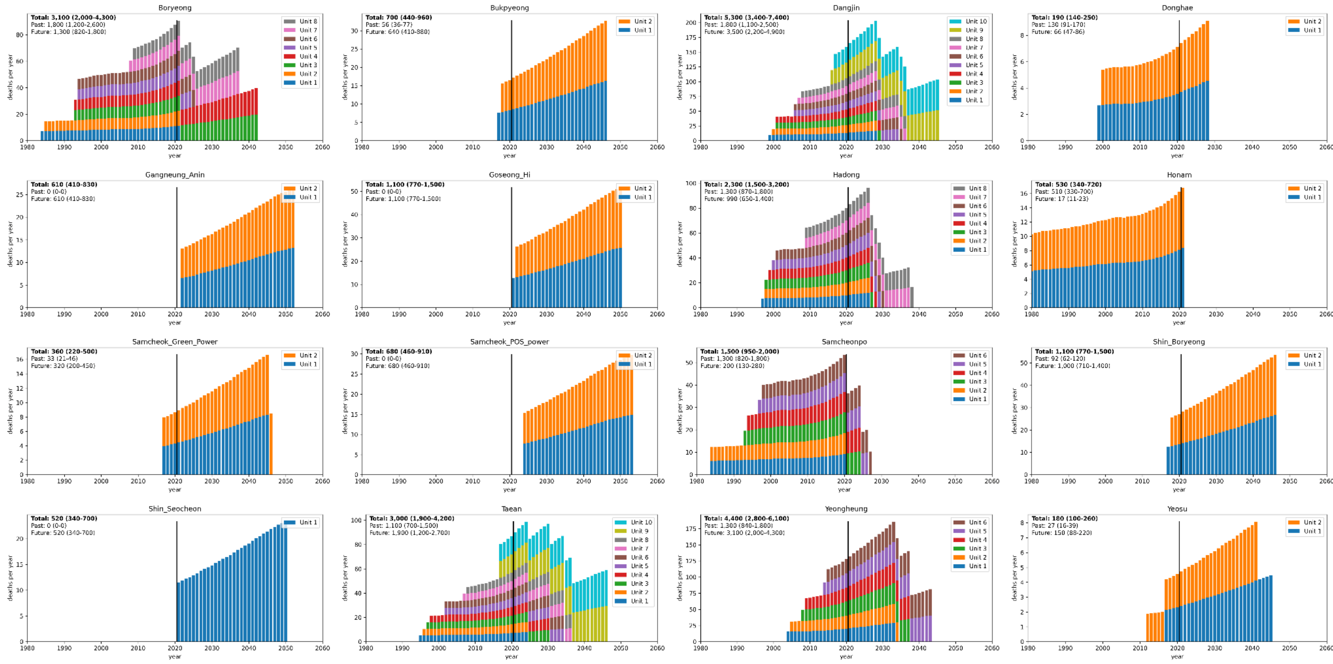


Figure A3.1: Health-impact related costs in South Korea due to air pollution from coal-fired power plants over their operation time, by plant and unit